Field Evaluation of Radon Fluxes from In-Service Disposal Facilities for Uranium Mill Tailings

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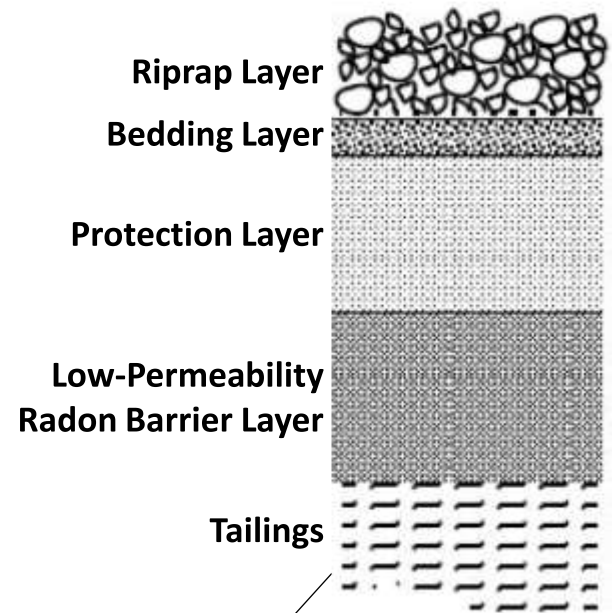
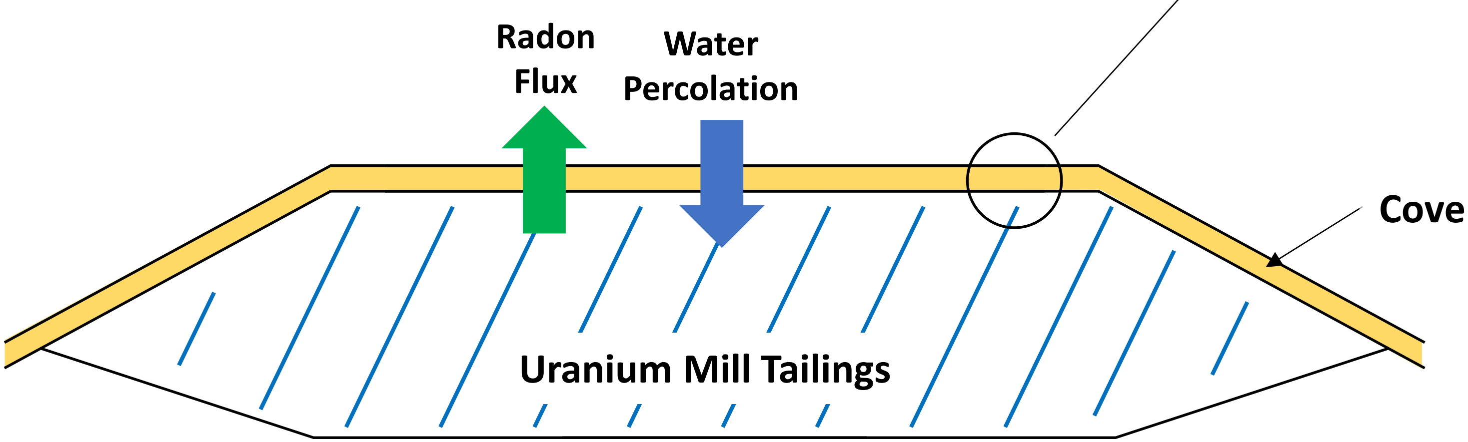
Typical Disposal Site – Design for 1000 yr



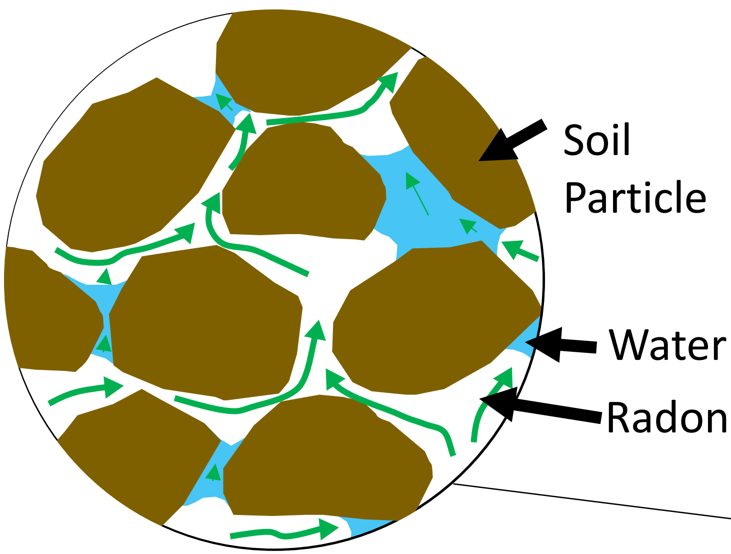


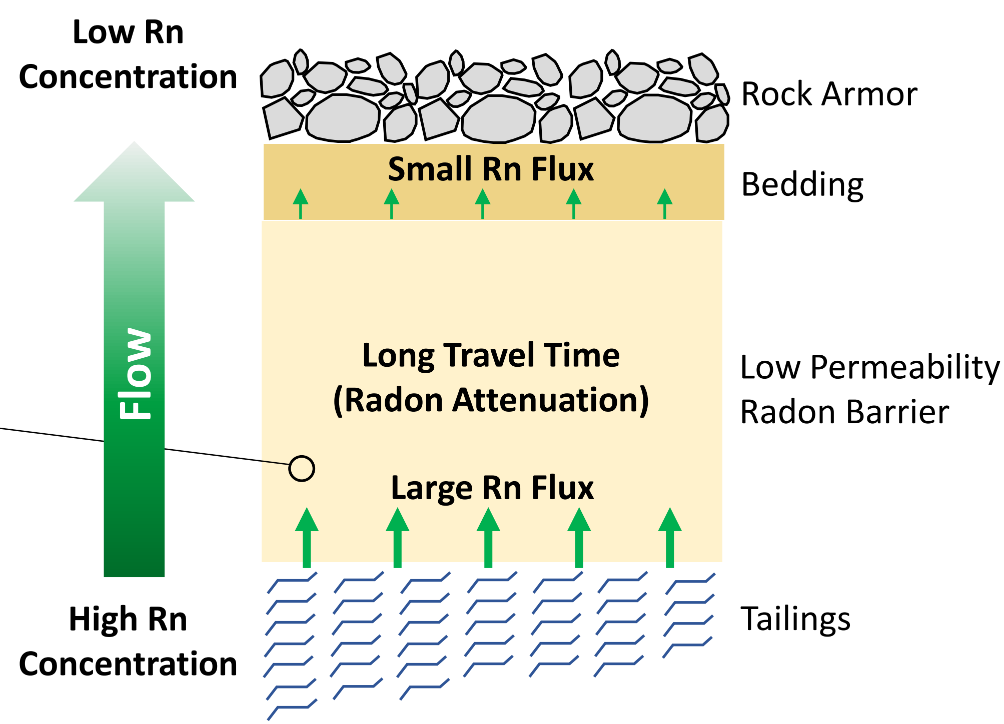
How do Radon Barriers Work?

- Radon transport primarily controlled by diffusion (high to low concentration)

$$J = -nD\frac{\partial C}{\partial z} \approx nD\frac{\Delta C}{\Delta z}$$

D_{air}: 10^{-5} m^2/s
D_{water}: 10^{-9} m^2/s
D_{solid}: ~ 0





Low diffusion coefficient and low flux when:

- High dry unit weight (solids content)
- High water saturation

B

Just Dry of Optimum

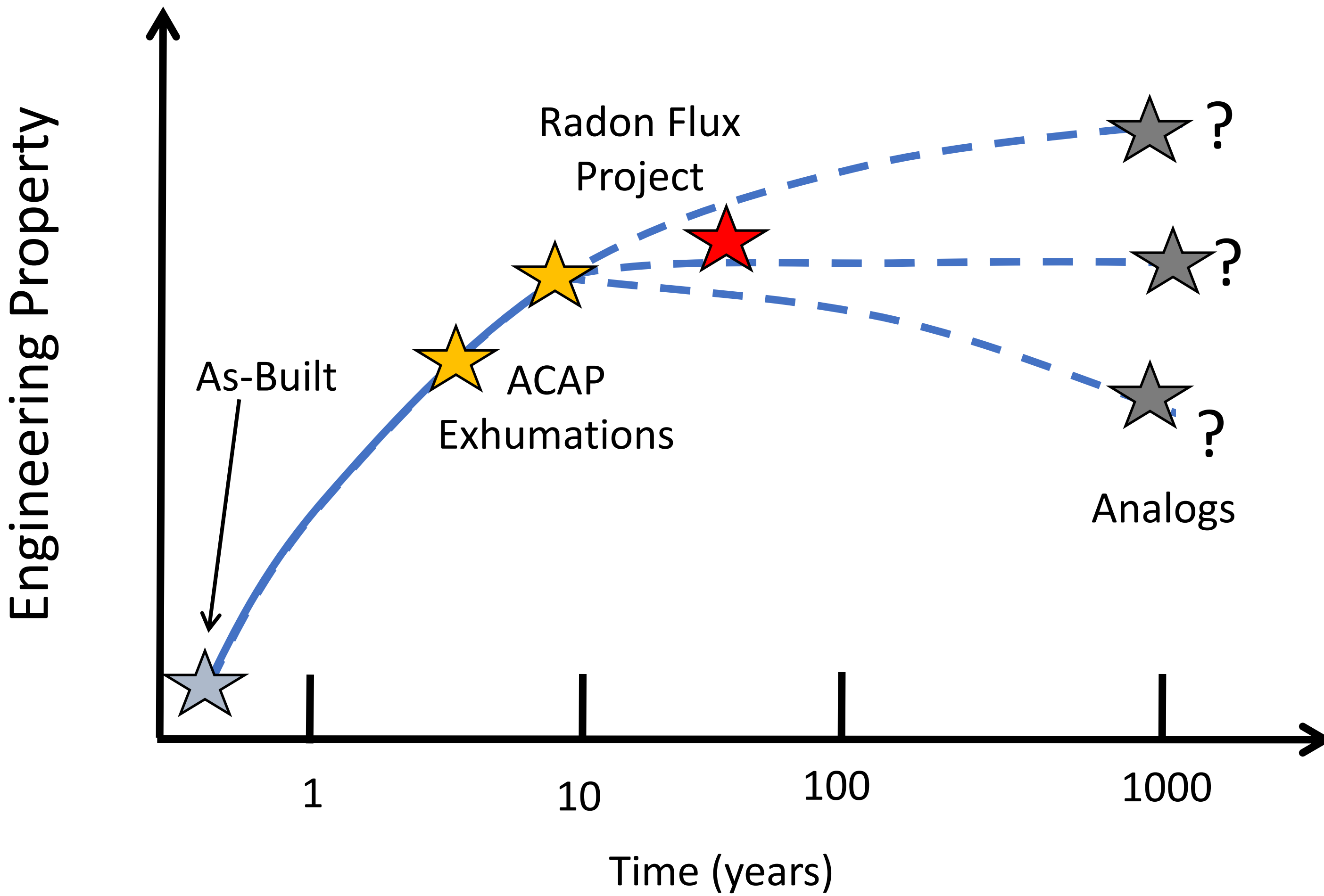
- Specimen compacted with standard Proctor energy (ASTM D 698) at w = 16% (1% dry of optimum)
- Large interclod pores are still visible, but clay is visible softer and more remolding is apparent
- K ~ 10^{-5} cm/s

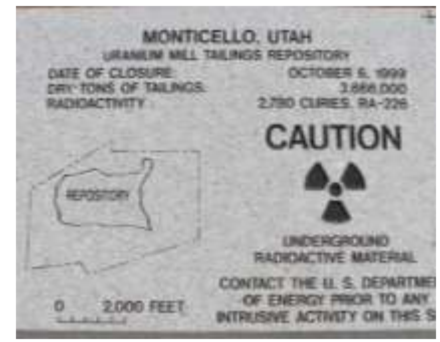
C

Wet of Optimum

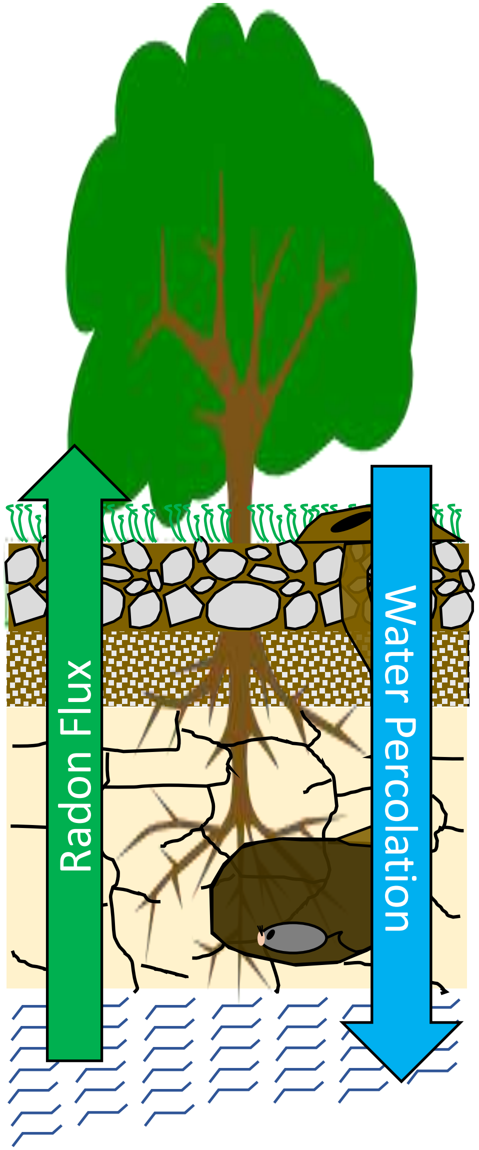
- Specimen compacted with standard Proctor energy (ASTM D 698) at w = 20% (3% wet of optimum)
- Only micro-scale pores exist. Clods fully remolded and interclod voids are eliminated.
- $K \sim 10^{-9}$ cm/s

Challenges – Predicting the Future





How will these barriers change over centuries?



Vegetative Succession

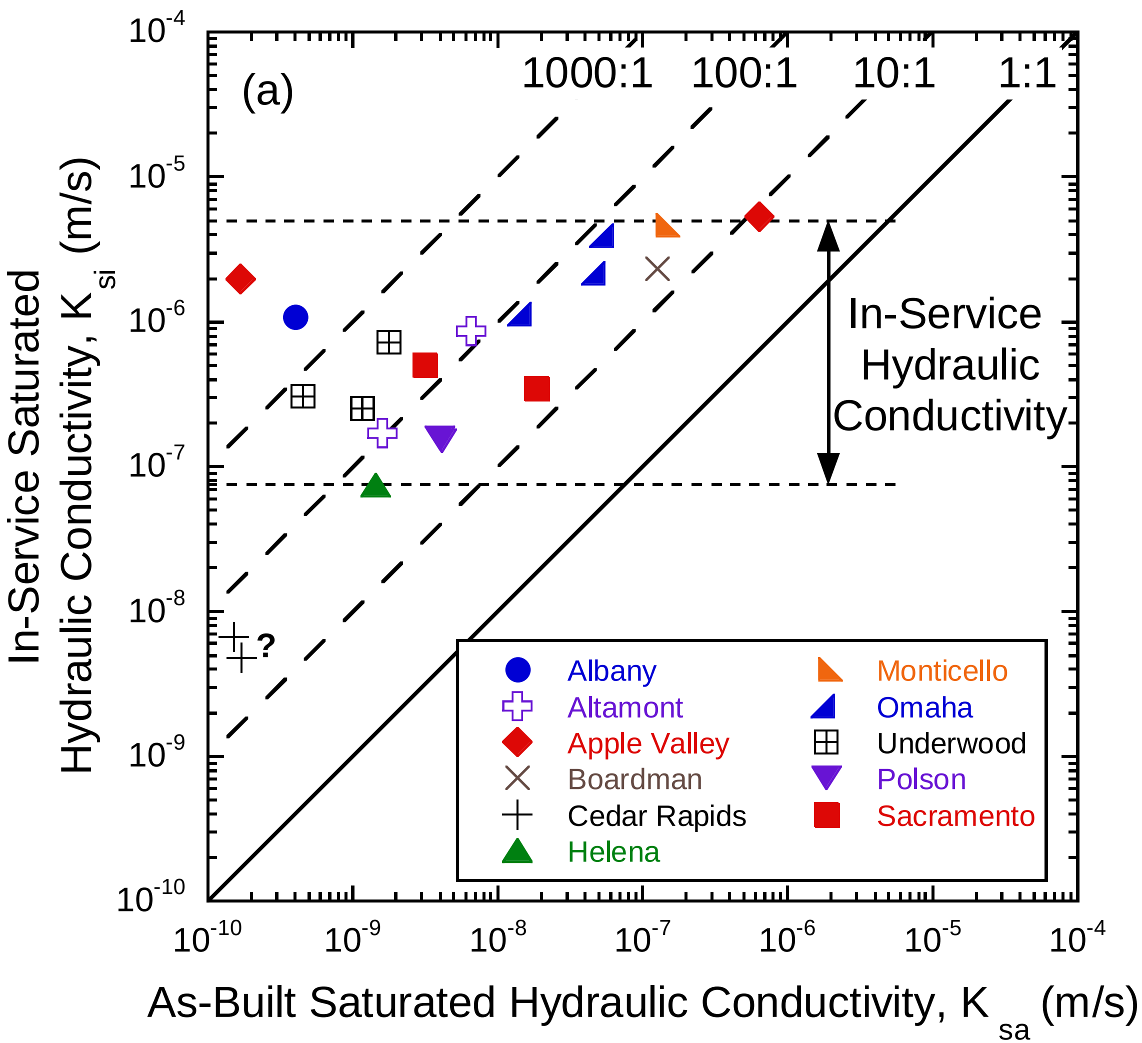
Dust Deposition

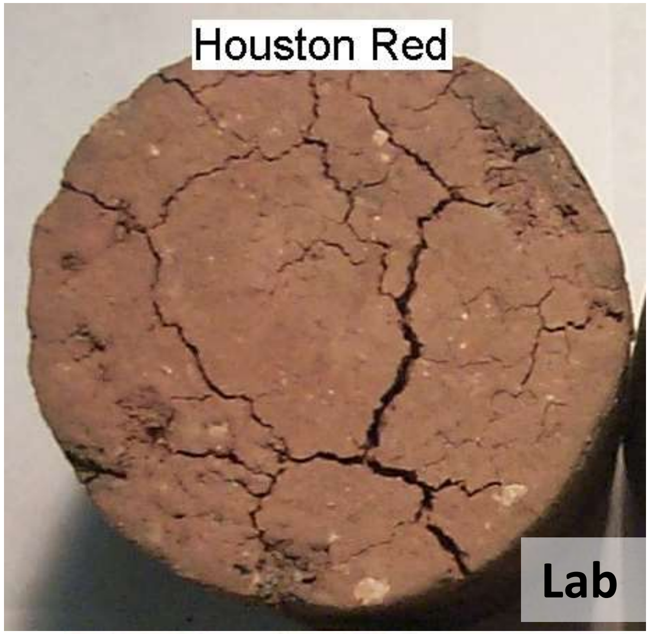
Soil Formation (desiccation cracking, freeze-thaw)

Bio-turbation

- Does pedogenesis soil cause changes in radon diffusion coefficient and flux?
- Does pedogenesis cause changes in hydraulic properties and percolation?
- Can we design barriers that are resilient in a natural system?

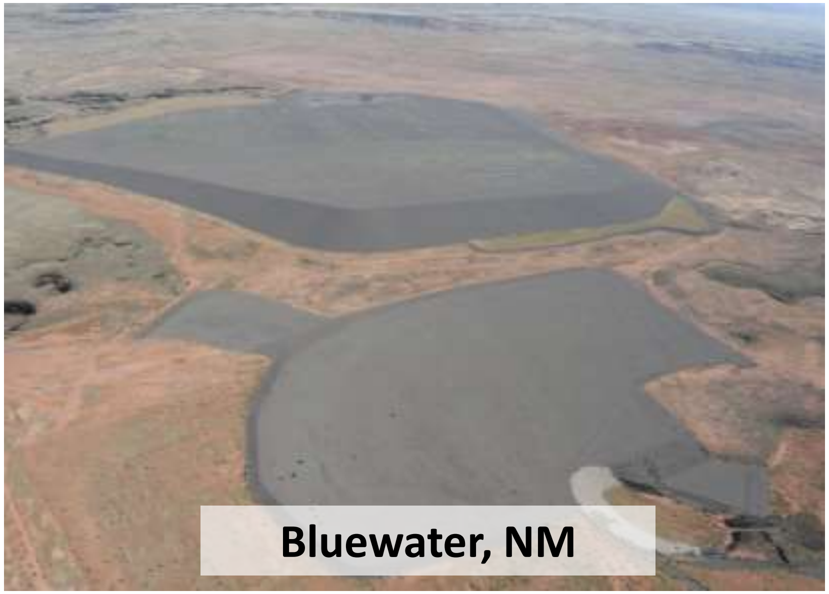
Pedogenesis in Barrier Layers





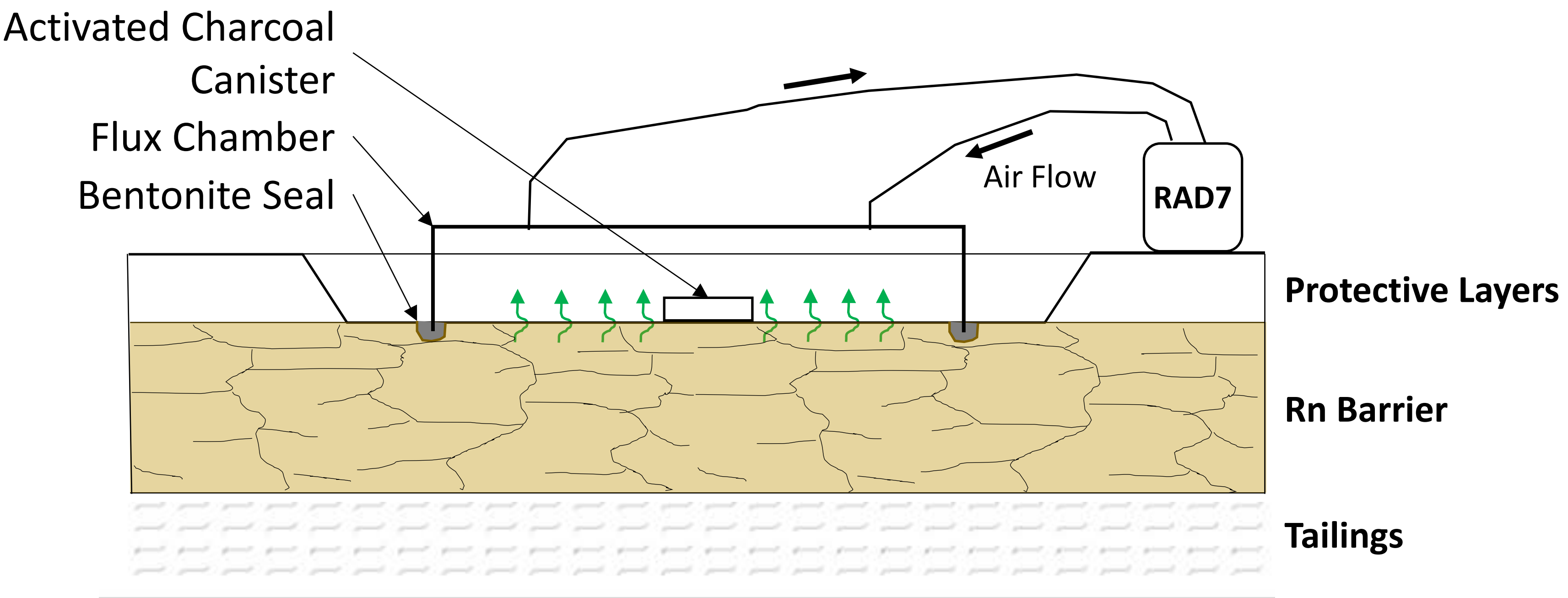
Similar Impact on Radon Diffusion?

Contrasting Climates for Field Sites

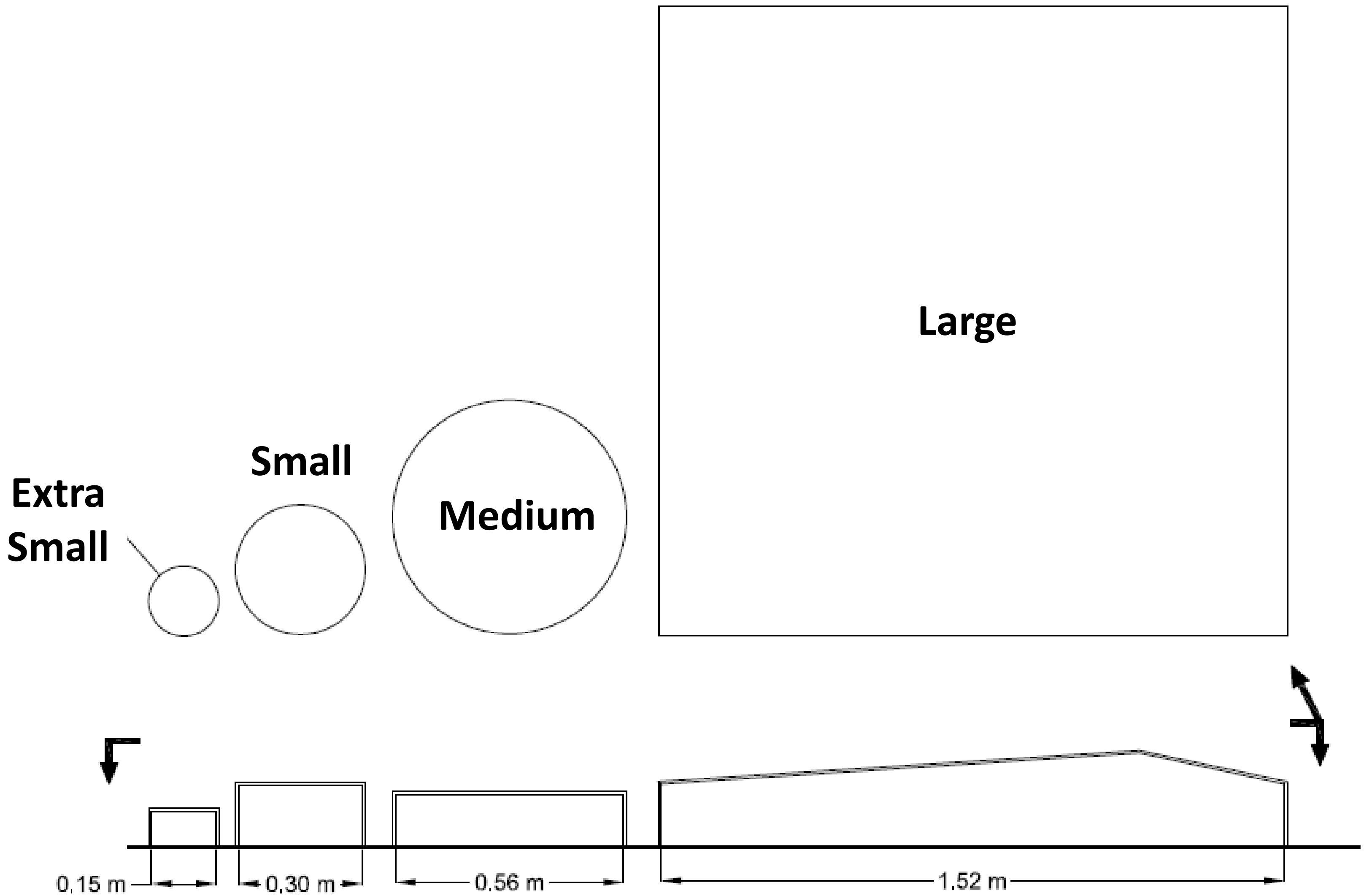


Measuring Radon Flux - Surface

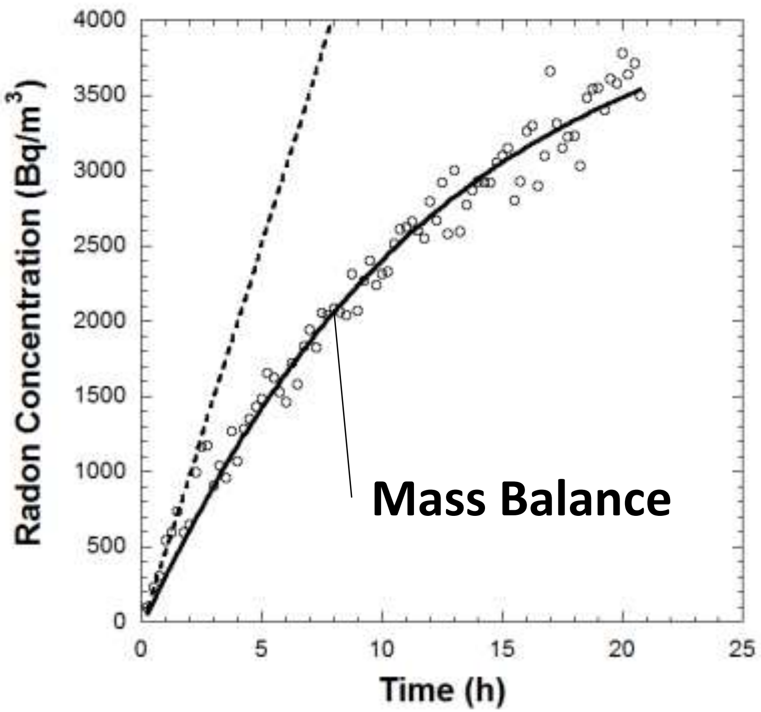
1. Expose Radon Barrier
2. Install & Seal Flux Chamber
3. Measure Radon Buildup



Flux Chamber: Small to Large



Calculating Radon Flux – RAD7 Data



Typical Radon Buildup Curve

Mass Balance

$$C(t) = \left(C_i - \frac{J_o A}{V(\lambda + D)}\right) e^{-(\lambda+D)t} + \frac{J_o A}{V(\lambda + D)}$$

Where:

Equation: Chao et. al. (1997)

$C(t)$ = concentration (Bq/m^3) at time = t (s)

C_i = initial Rn conc. in chamber (Bq/m^3)

J_o = the initial Rn Flux rate (Bq/m^{2}s)

A = area of surface (m^2)

V = the volume of the chamber (m^3)

λ = the decay constant (s^{-1})

D = the back diffusion rate (s^{-1})

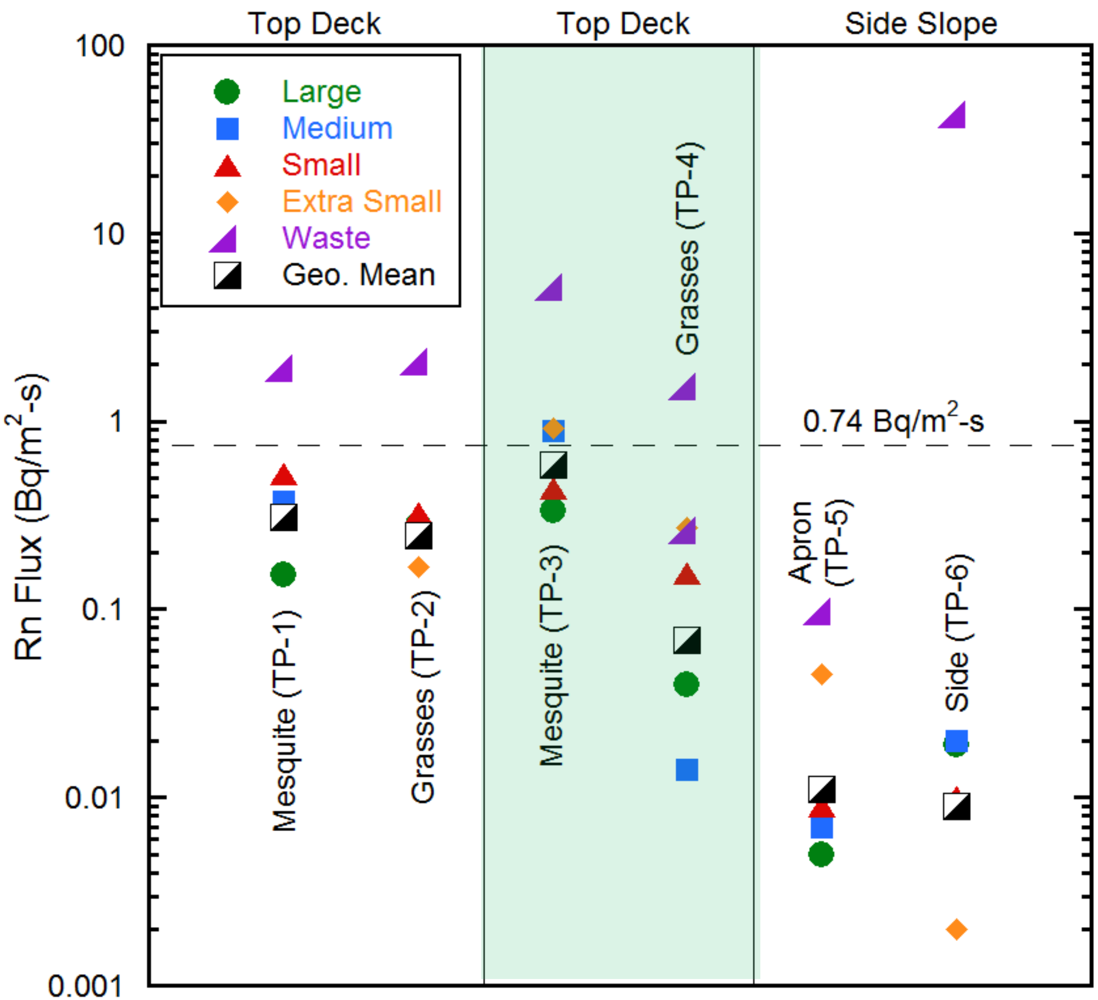
Methodology accounts for back diffusion from mass build up.

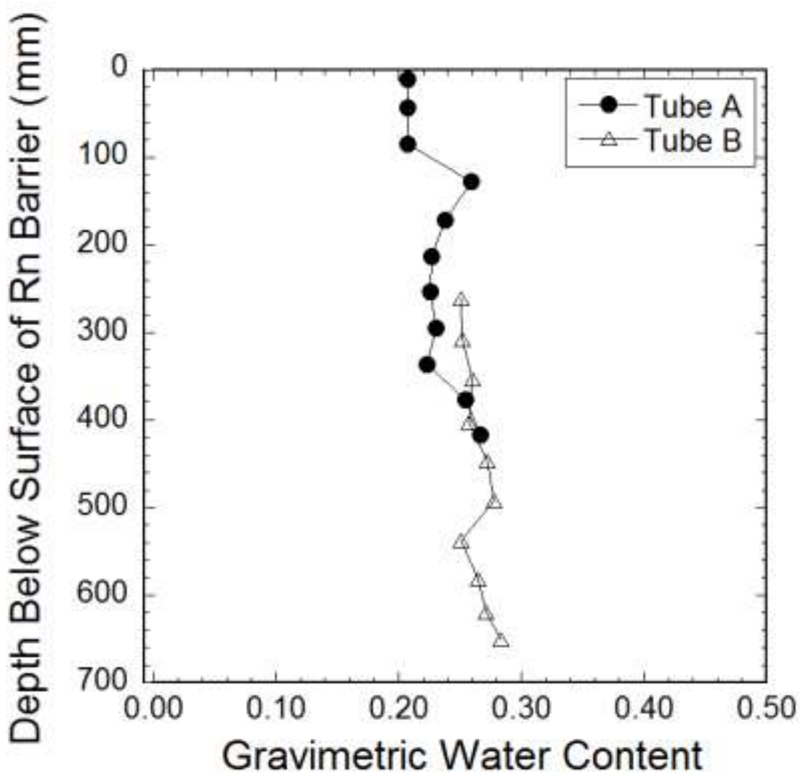
Surface Feature

Installation of Flux Chambers

Test Duration: 5 – 20 hours

Falls City – Vegetation & Scale Effects





Results – Riprap Slope vs Top Deck

Falls City, TX

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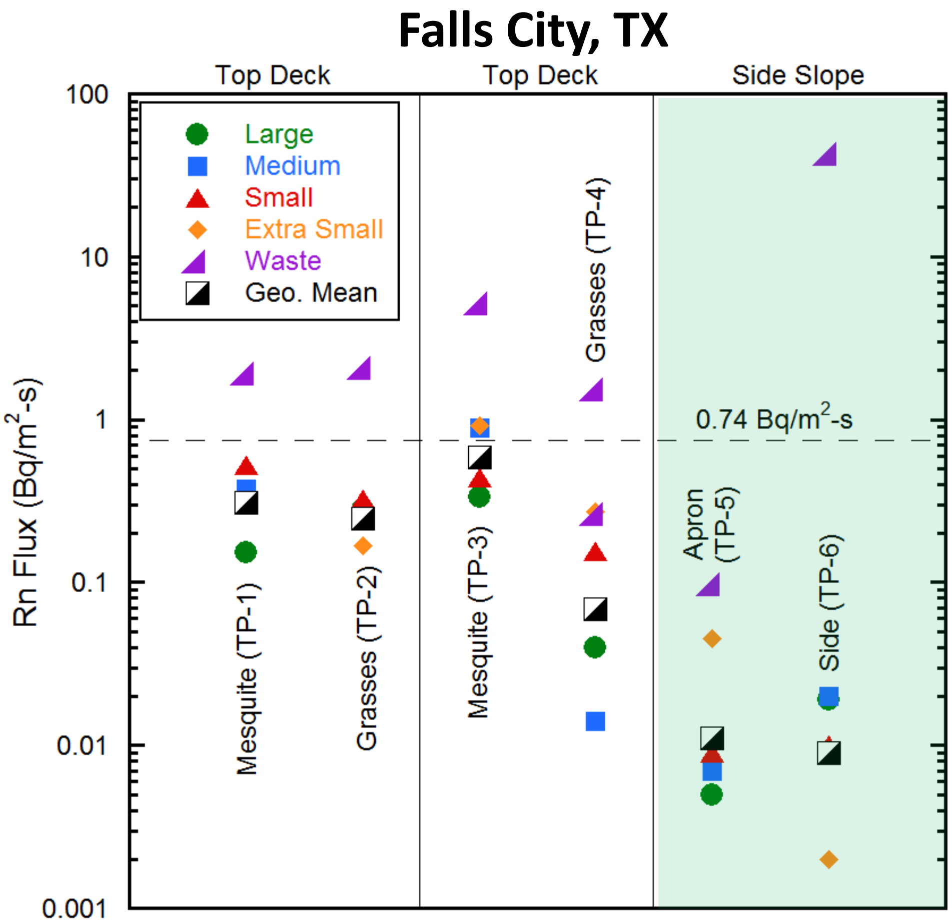
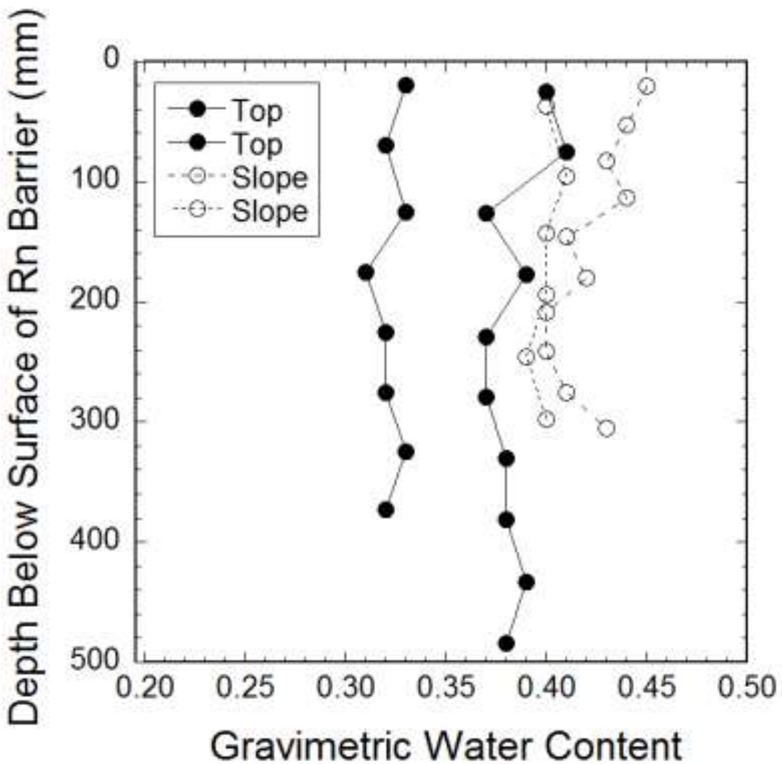
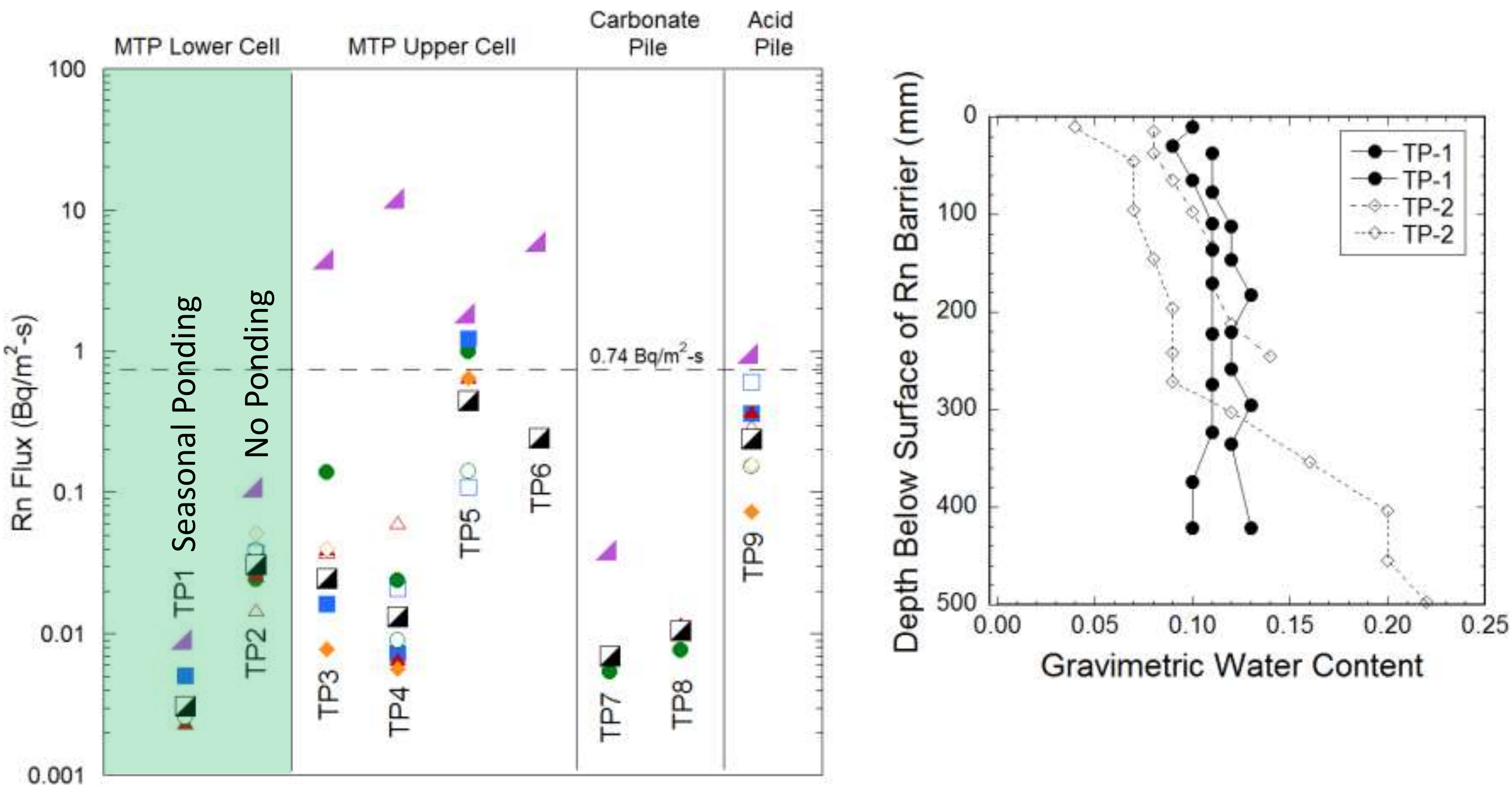




Riprap 'mulch' retains water -- increasing water saturation.

Results – Seasonal Ponding

Impact of Water Saturation from Seasonal Ponding

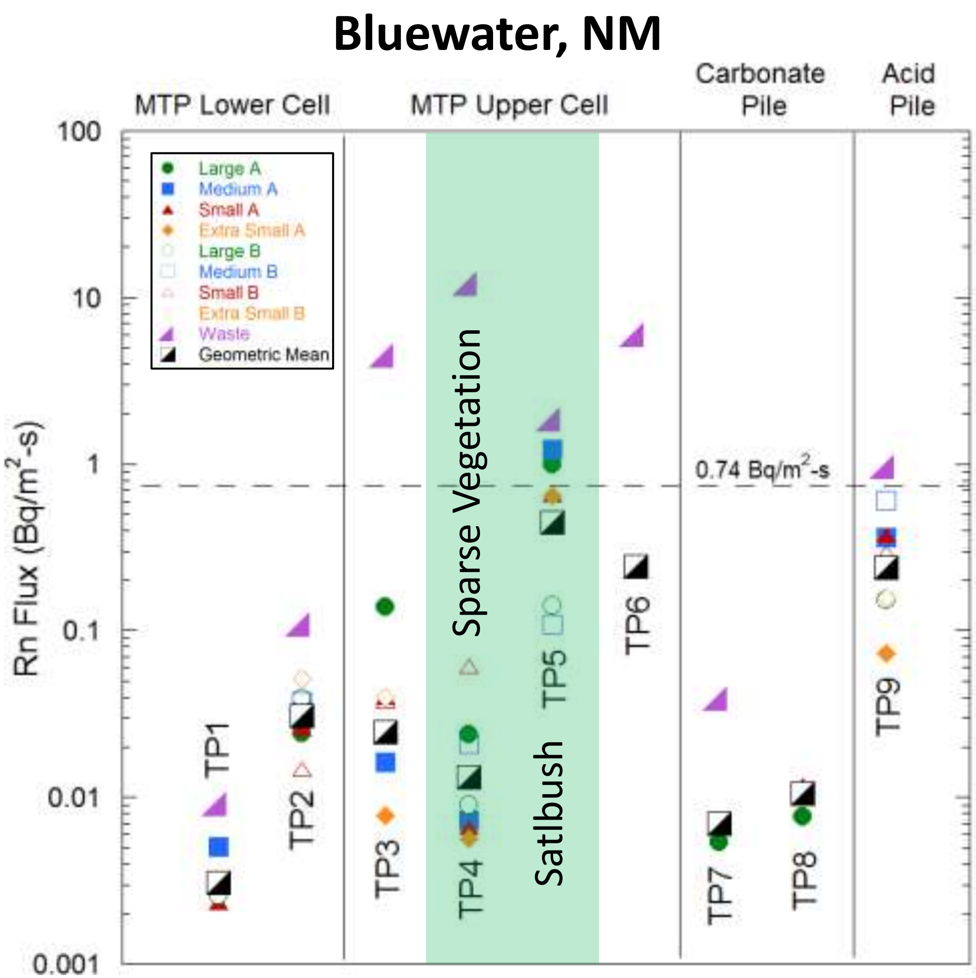


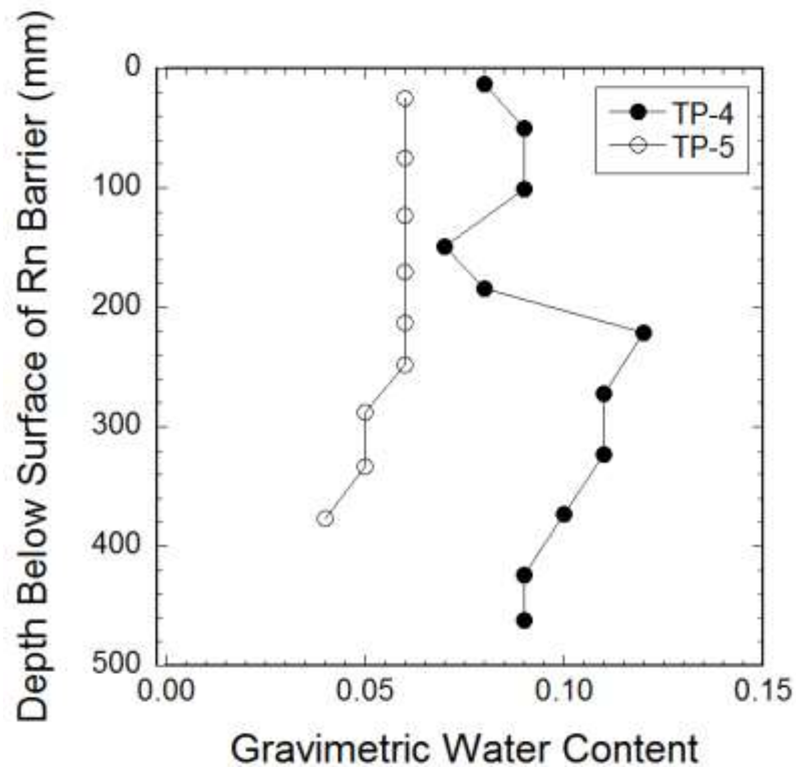
Higher water saturation – lower Rn flux

Nearly all fluxes below regulatory limit

Deep Rooted Vegetation

Results – Deep Rooting Vegetation





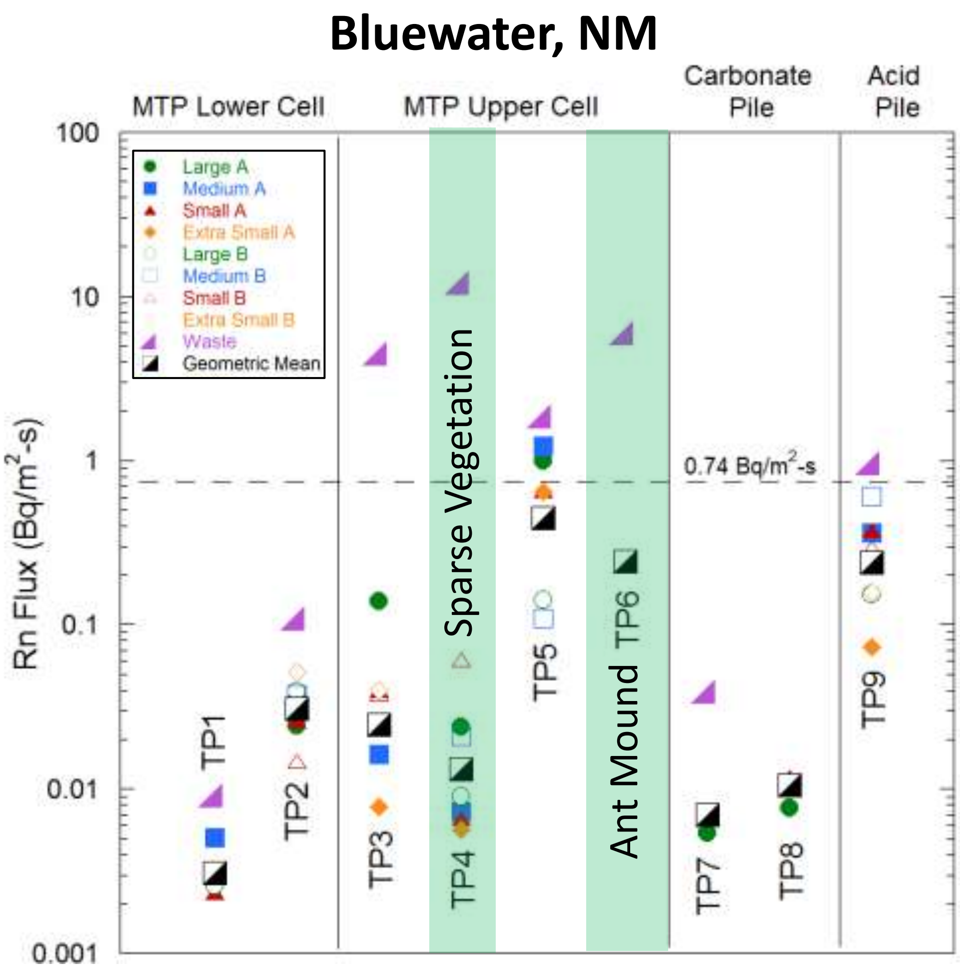
Higher water saturation – lower Rn flux

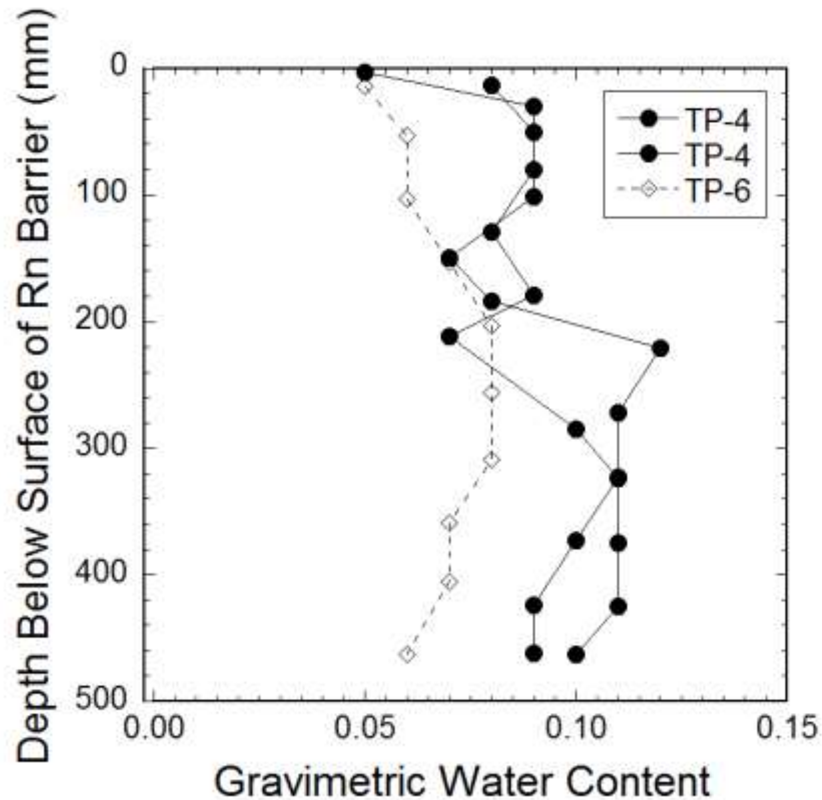
Macrostructure contribute?

Ant Mound at Bluewater, NM


Approximate Limits of Ant Tunnels

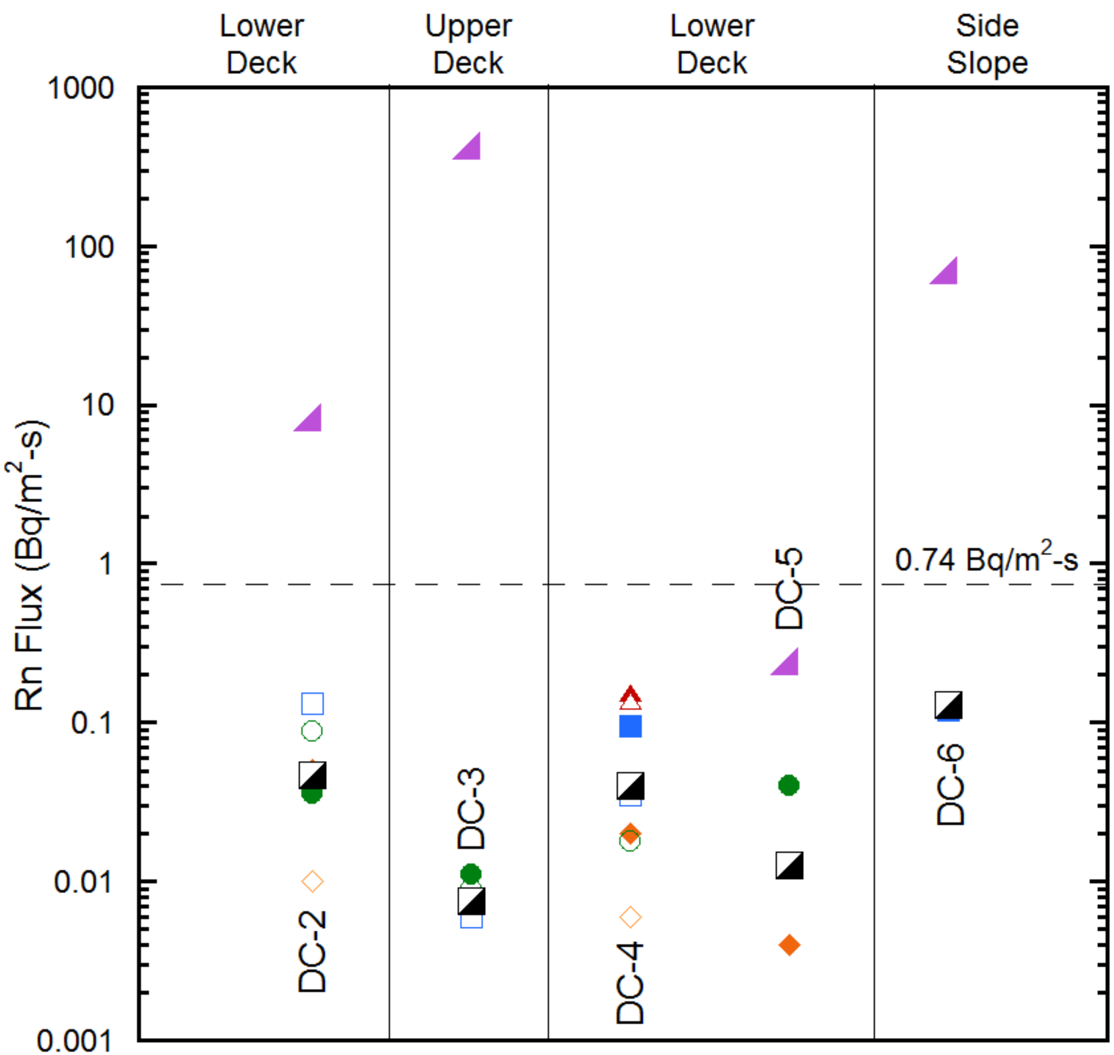
Fluxes at Ant Mound





Ant mound yields lower water saturation -- passive venting. Macrostructure contribute?

Fluxes at Shirley Basin South



- Very low Rn flux at site.
- High flux from tailings.
- Rn barrier is performing very well.

Lessons Learned

- Fluxes below regulatory requirement, but higher than as-built (4-10x). What is long-term condition?

- Fluxes higher below features that contribute to lower water saturation (ant mound, salt bush). Can we control long term?

- No apparent scale effect – similar fluxes with large-scale and smaller flux chambers.